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Circumferential MFL In-Line Inspection for Cracks in Pipelines

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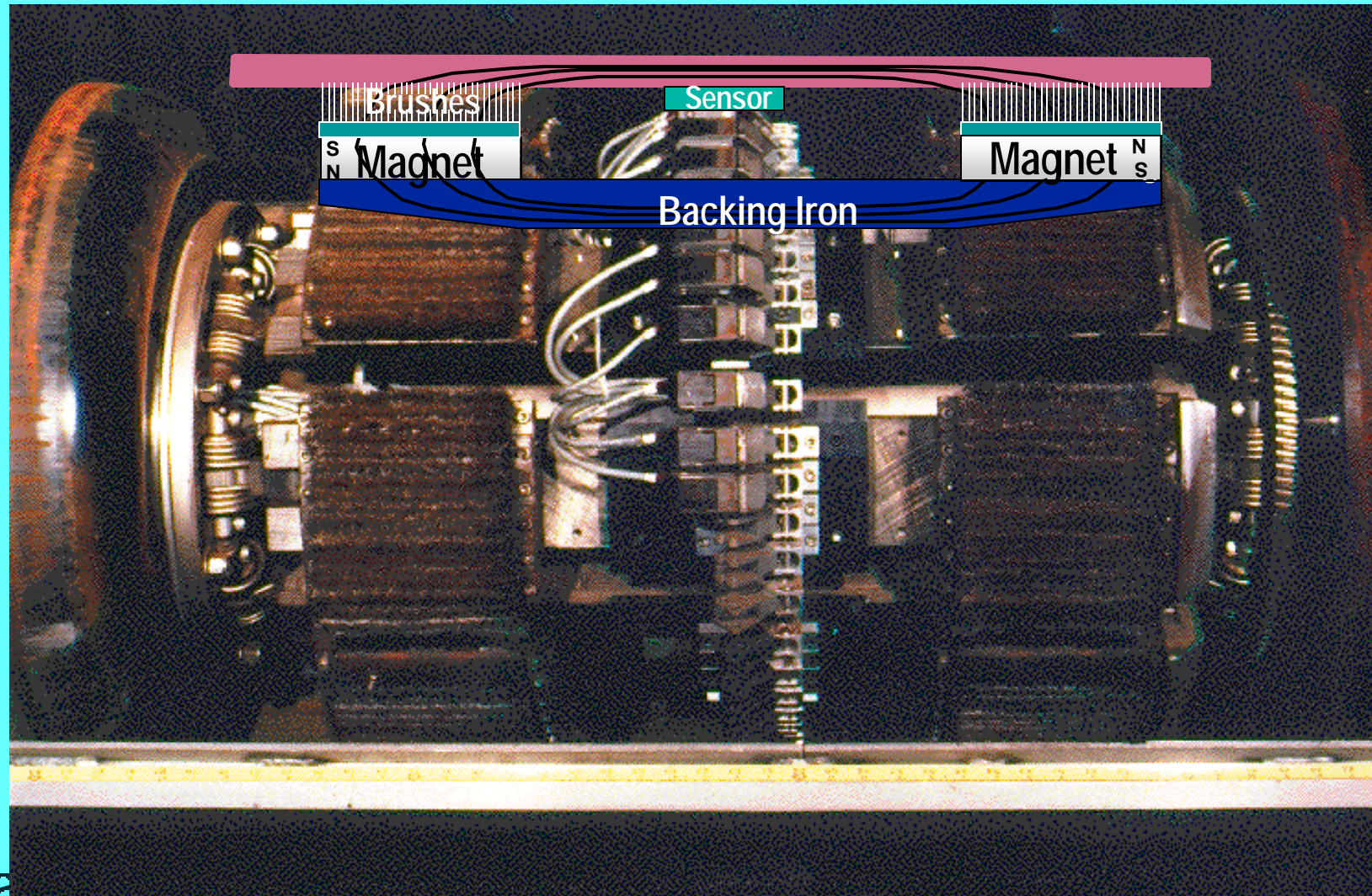
Project Objective

- The objective of this project is to evaluate and improve the capability of using circumferential magnetic flux leakage (MFL) inspection to detect and size axially oriented cracks in natural gas and hazardous liquid pipelines.
- This will be accomplished by developing
 - Noise filtering algorithms
 - Stress detection algorithms
 - Data analysis methodology using filtered signals and the stress detection algorithms.

Presentation Outline

- Background
- Circumferential MFL Research Pig Design
- Circumferential and Axial Magnetic Properties
- Flux Leakage Signals from
 - Weld Deposition Cracks and EDM Notches
 - Natural Stress Corrosion Cracks and Corrosion
- Pipe Noise – Magnetic signals for Circumferential and Axial MFL
- Conclusions
- Future work

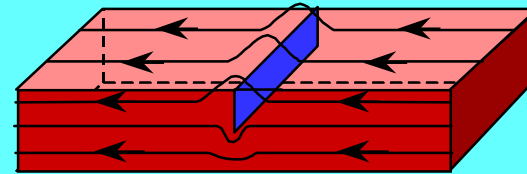
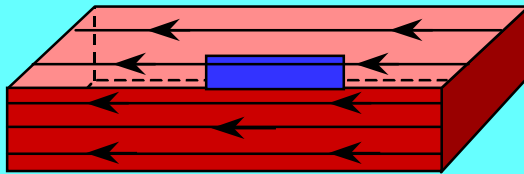
MFL Axial Magnetizer



Barrene

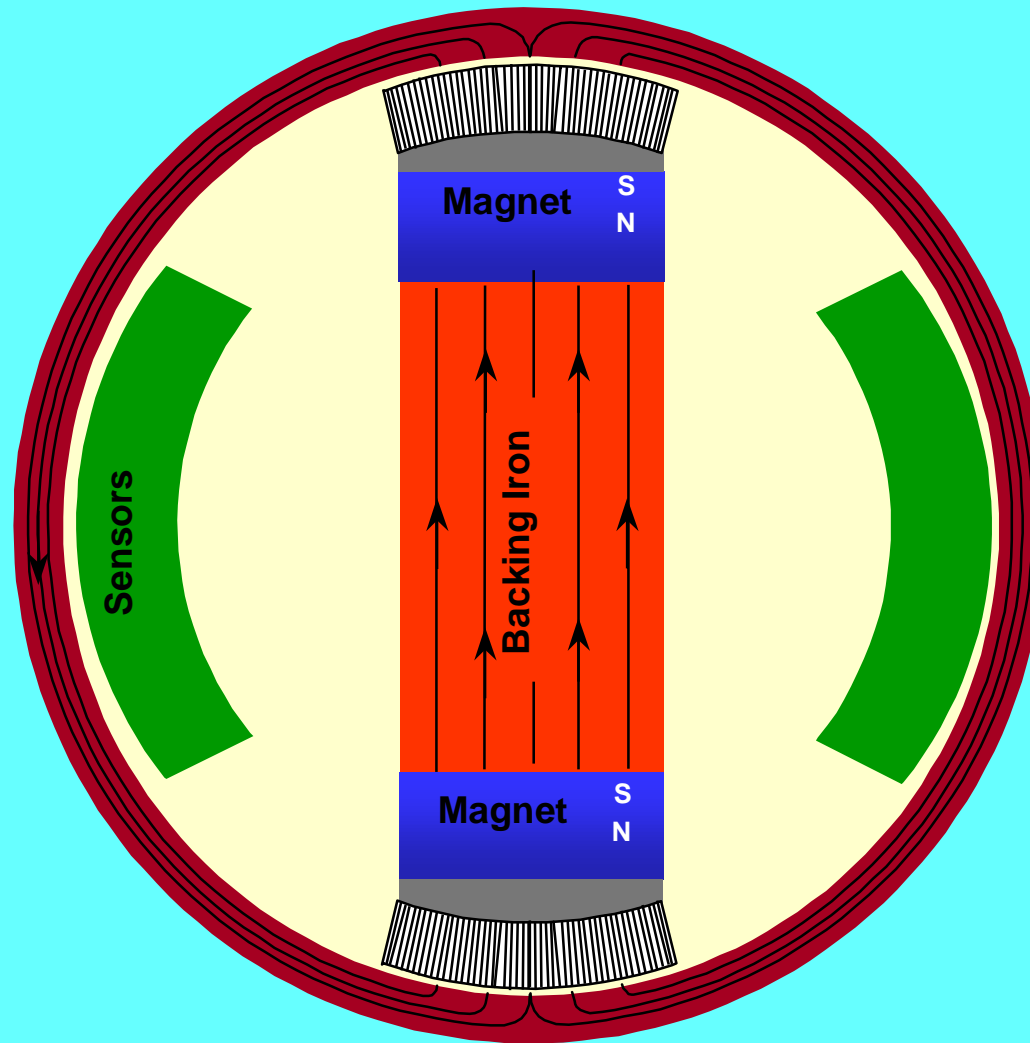
Cracks

- Axial MFL cannot find cracks. Why not? Because the magnetic flux is parallel to the cracks.



- But magnetic particle inspection (a flux leakage method) is a proven method for detecting cracks. Why does it work? Because the magnetic flux is orthogonal to the cracks.

Circumferential Magnetic Flux Leakage



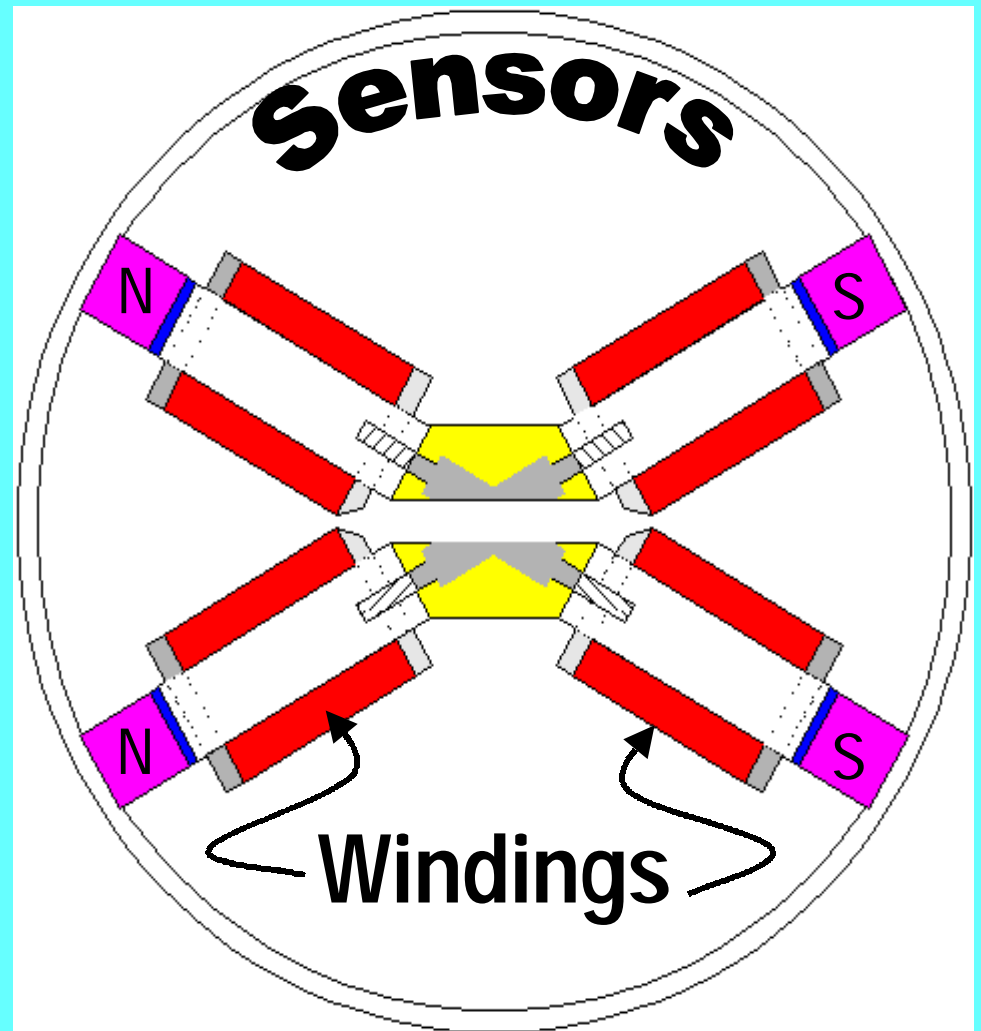
Circumferential MFL Research Tool Design

Goal: Design and build a magnetizer that

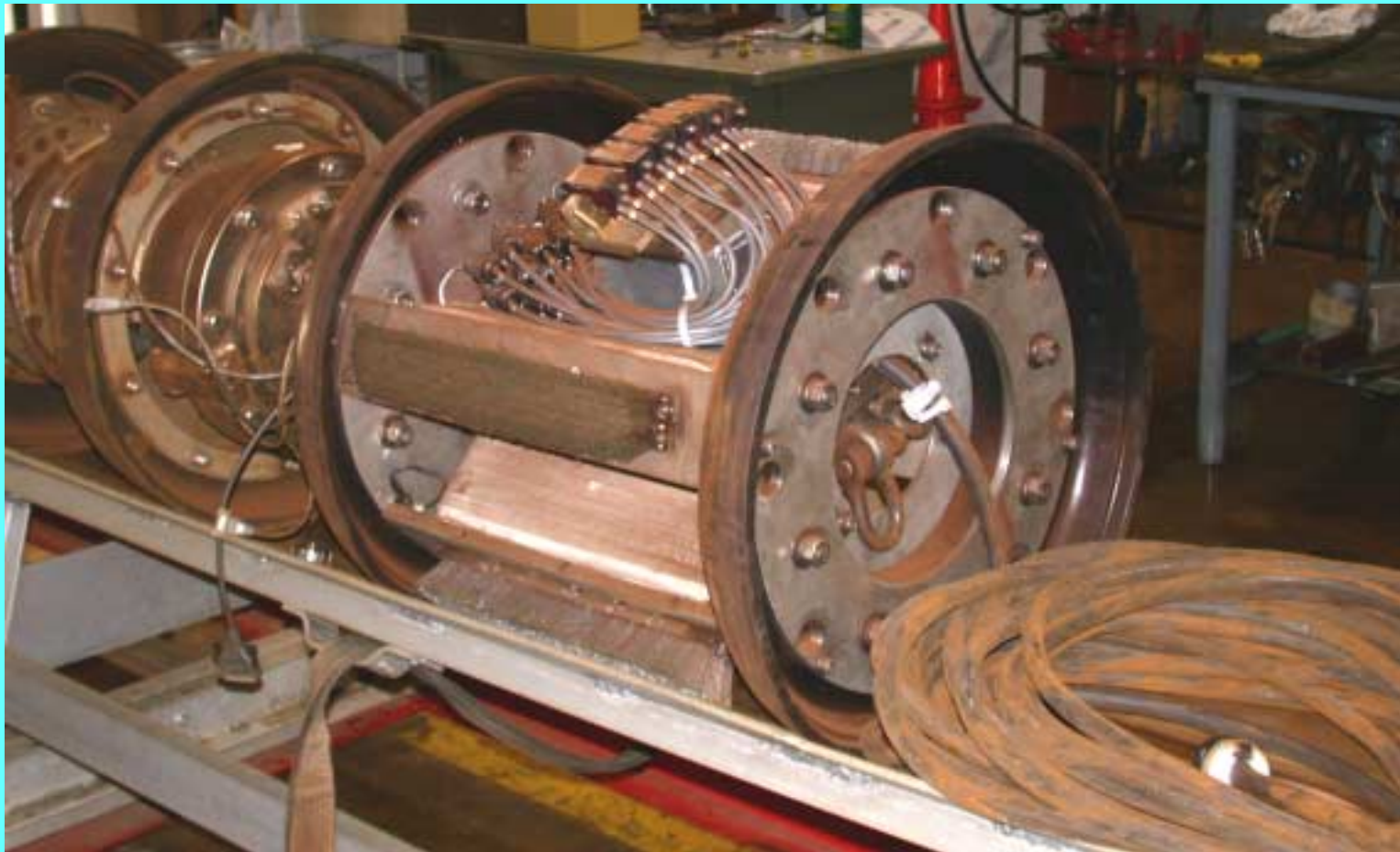
- Saturates the pipe material in the circumferential direction, greater than 120 Oersted.
- Can produce either high and low field levels to examine stress effects
- Has a large area of uniform magnetic field
- Builds on the experience of previous tool designs

Electromagnet CMFL Research Tool

- 120 degree sensor region
- Unique Pole configuration
 - Like Poles separated by 60°
 - Opposite poles by 120°
- Electromagnet for variable field levels
- Finite element modeling used to design components
 - Proven models of brushes and core materials
 - Published magnetization curves for circumferential magnetic properties

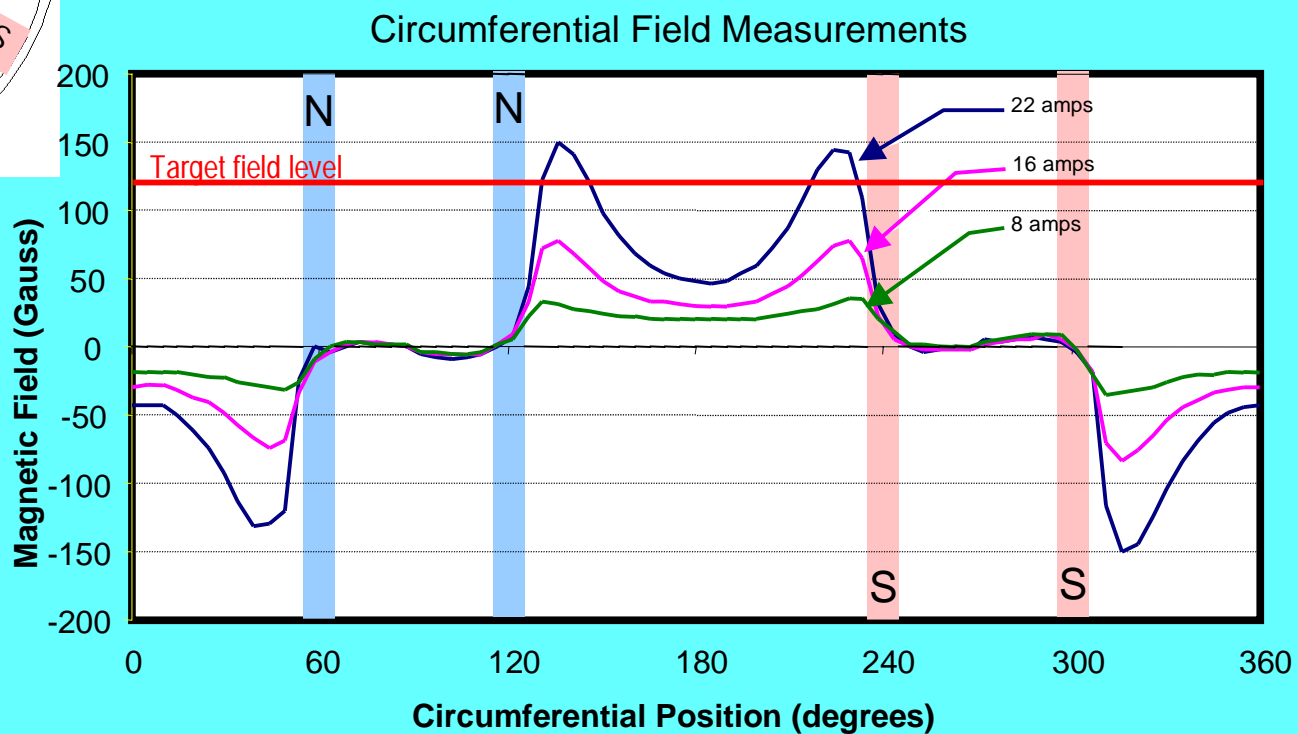
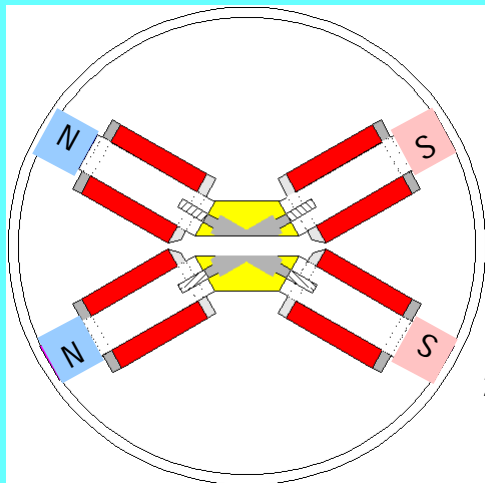


CMFL Research Magnetizer

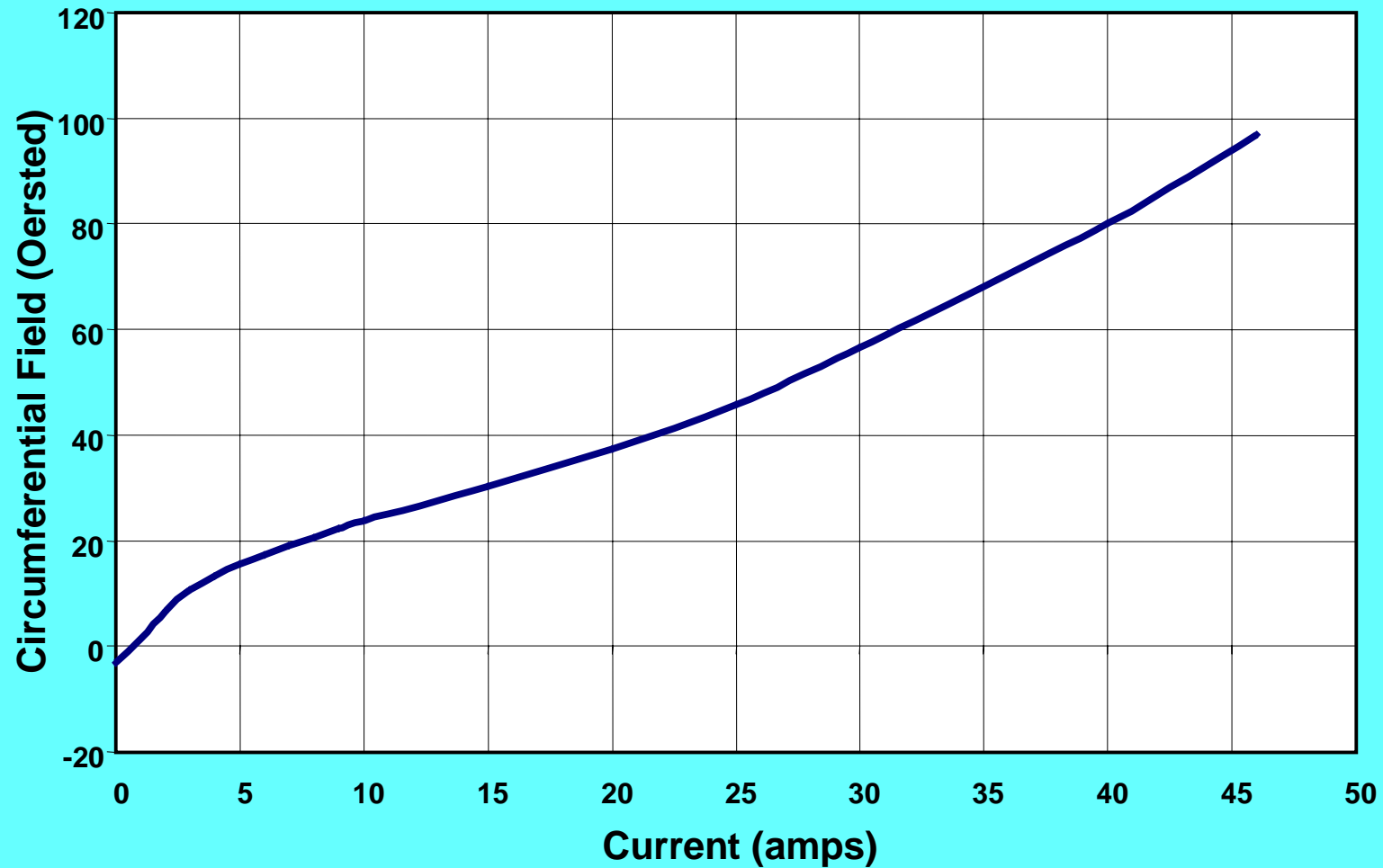


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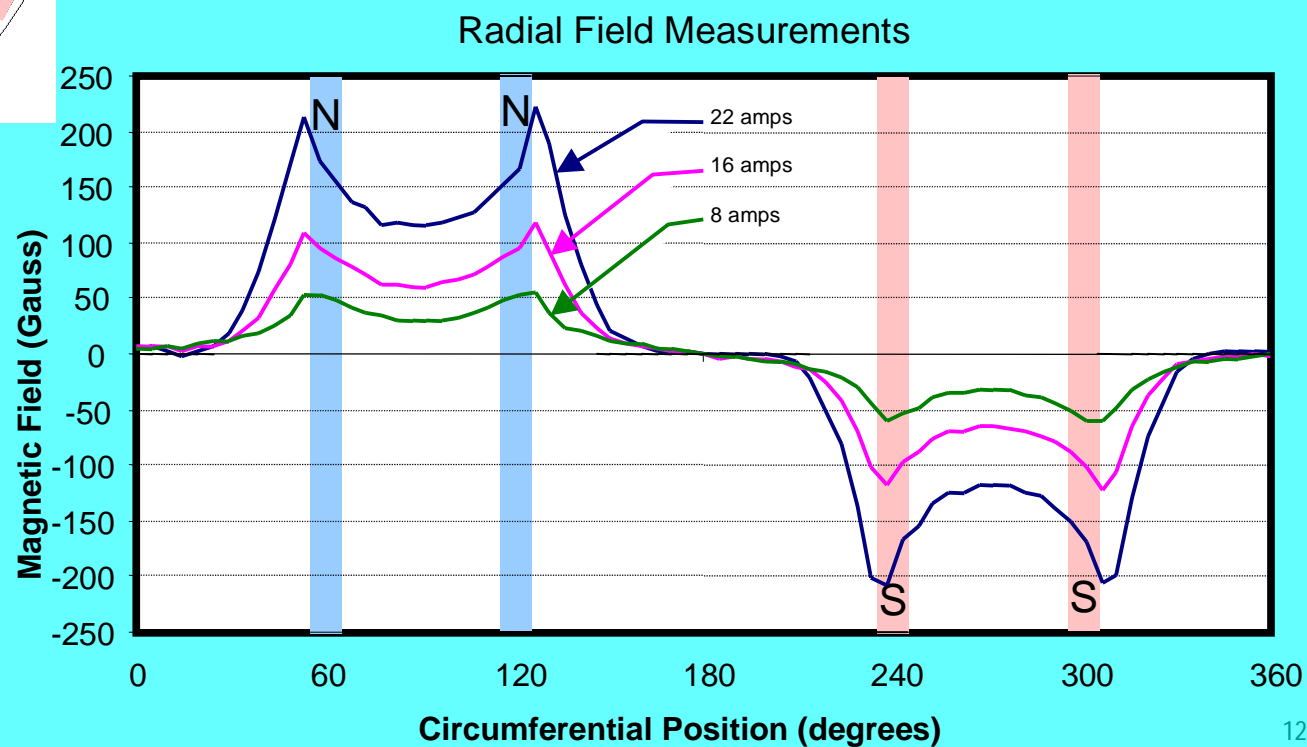
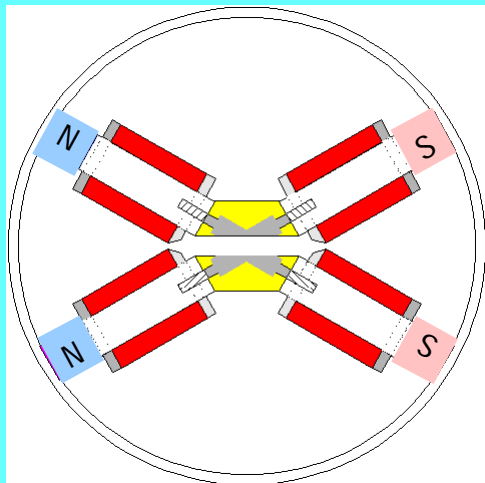
Magnetizer Performance – Circumferential Field



Field versus current level

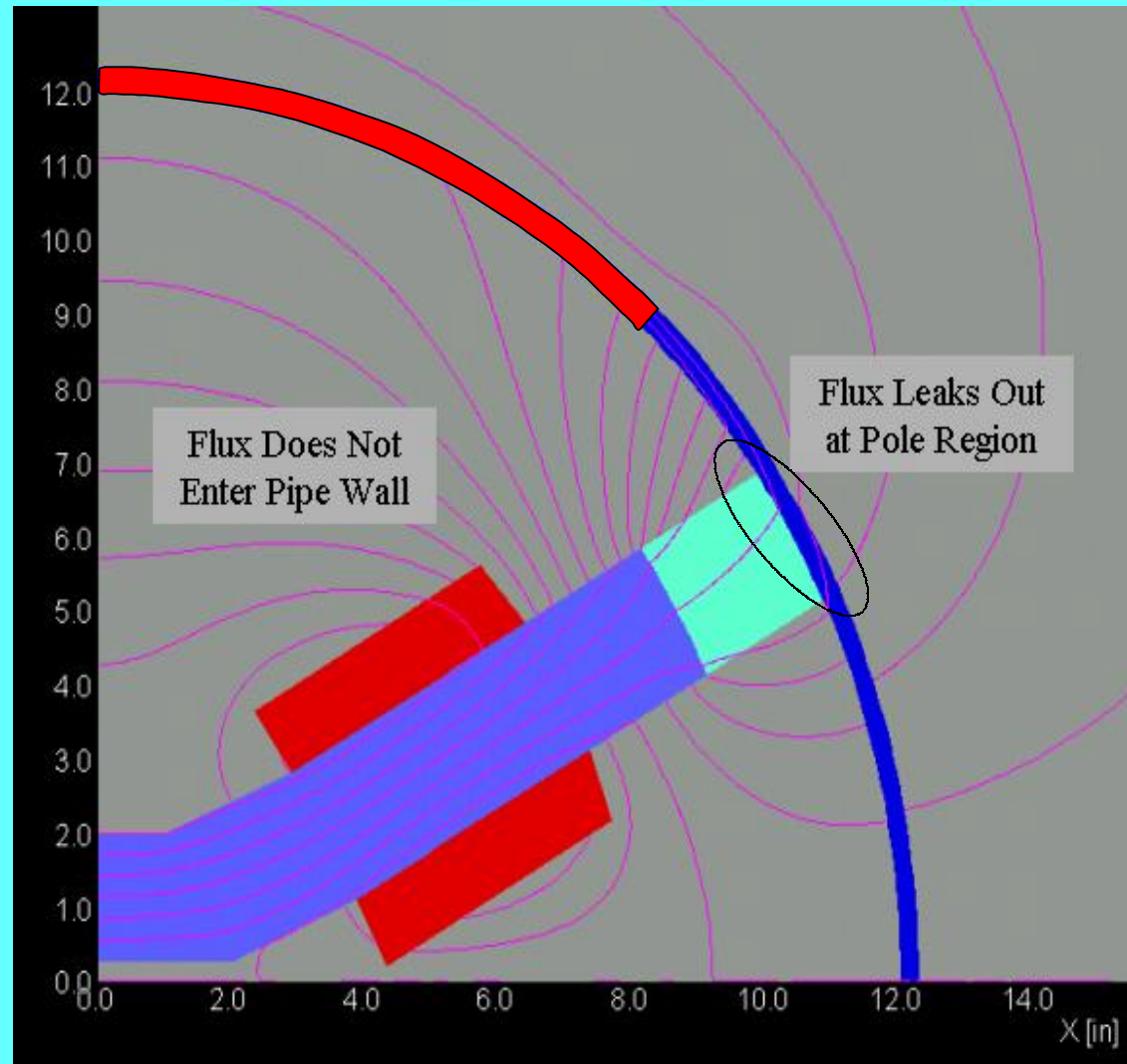


Magnetizer Performance - Radial Component

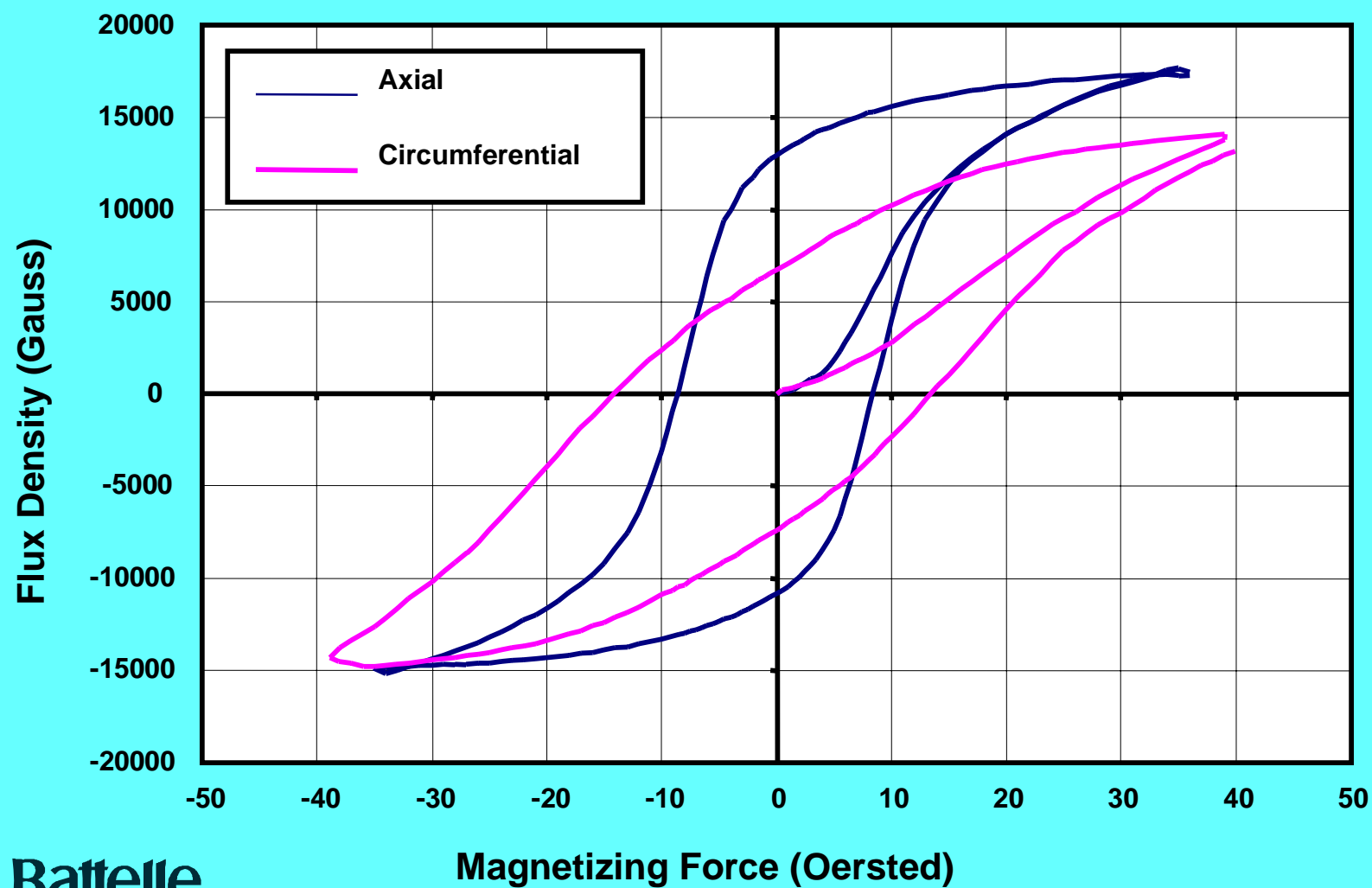
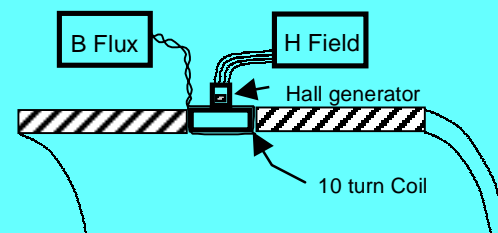


Flux Line Plot

- Pipe Wall Near Pole Pieces is Saturated. Flux Leaks Out of Pipe Wall. Effective Permeability ~ 15
- Flux Does Not Enter Pipe Wall Between Opposite Pole Pieces. Seeks New Path.
- Roughly Twice as Difficult to Magnetize Pipe in Circumferential Direction. Effective Permeability of 75.



Magnetization Curves

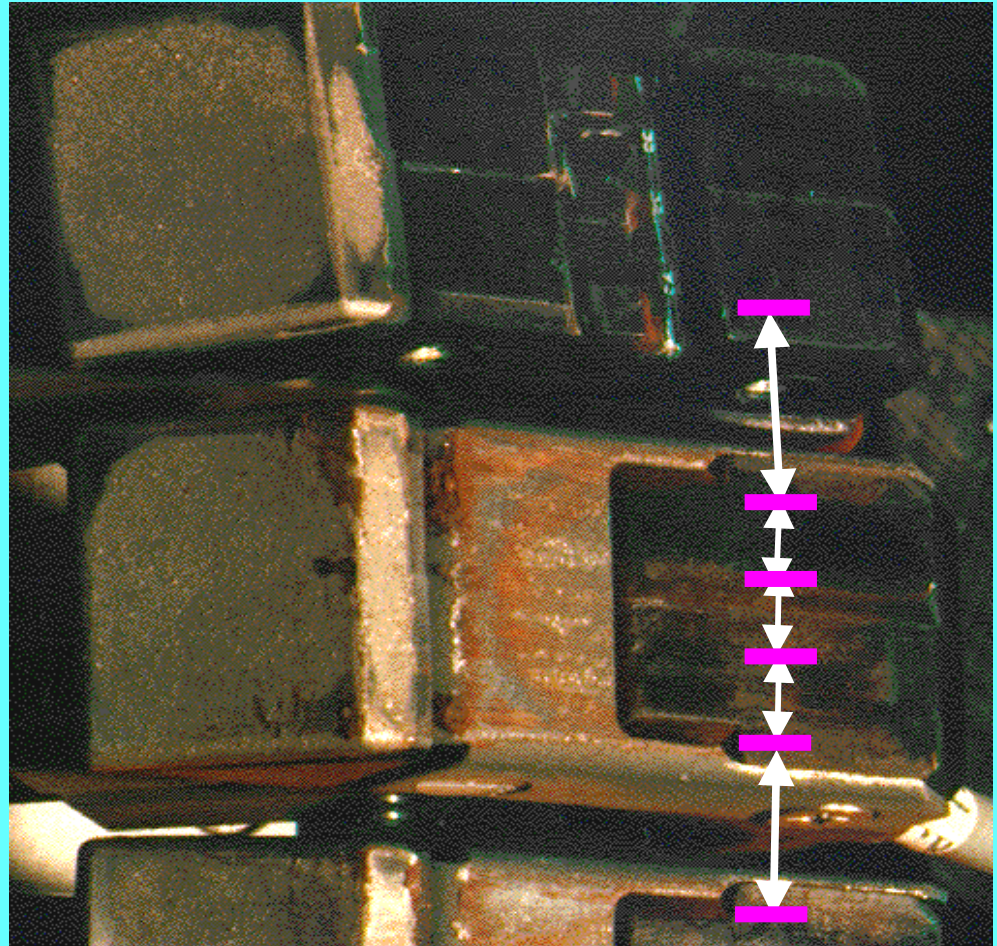


Magnetizer Performance Summary

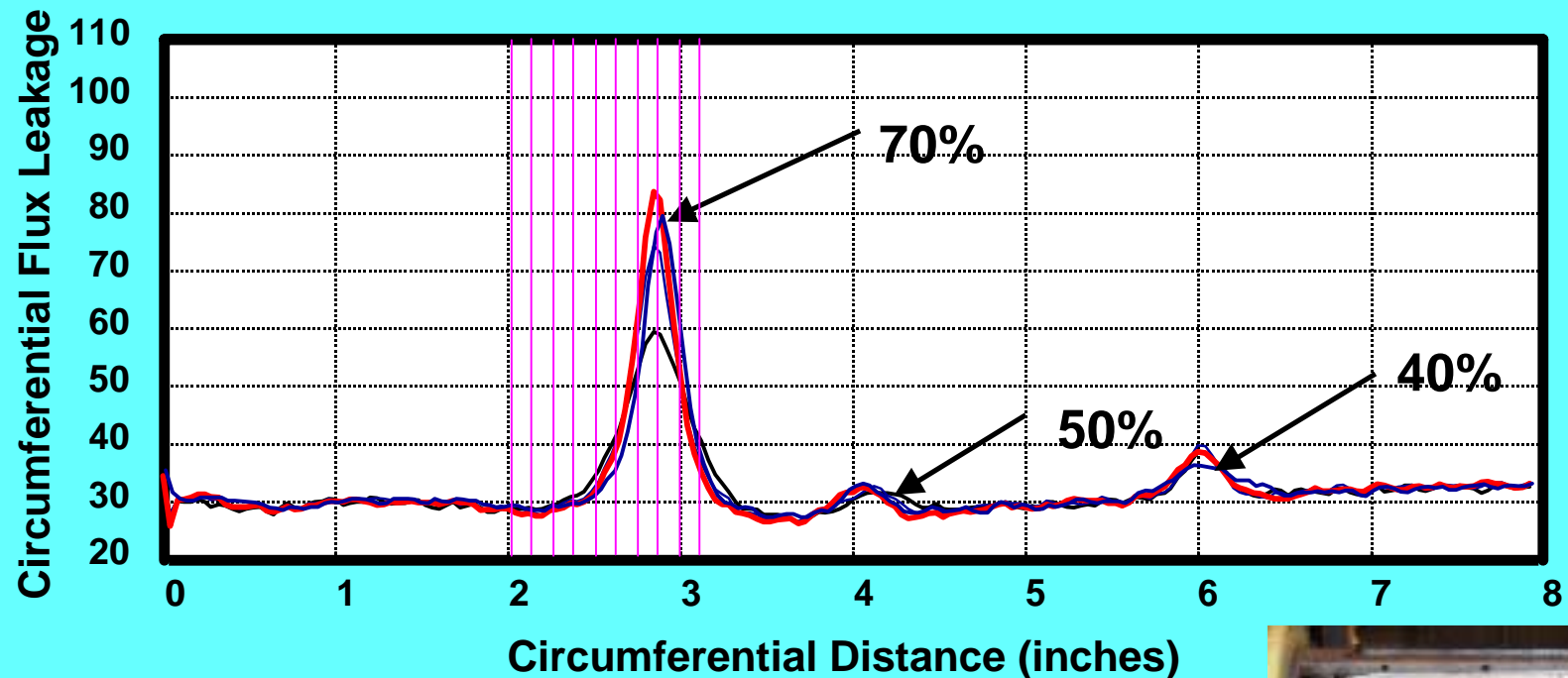
- It is much more difficult to saturate the pipe material in the circumferential direction
 - In situ measurements show that permeability in the circumferential direction is a quarter of the axial permeability
- Iterative modeling showed the pipe material at the magnetizer saturates (permeability ~ 15) while the material midway between the poles is able to carry more flux (permeability ~ 75)
- The nearly linear relationship between current and flux density indicates the magnetic properties of the pipe do not significantly influence the magnetic circuit

Flux Leakage Sensors

- Hall effect sensors to measure the magnetic field
- Sensor circumferential spacing important for narrow defects
 - Sensor to sensor spacing
 - Sensor head gap



The width of a crack



- Gaps of $\frac{1}{4}$ inch could under report crack amplitude by 50%
- Gaps of $\frac{1}{2}$ inch could miss the crack
- The TBV has $\frac{1}{16}$ inch gaps for each head and interleaved heads



Flux Leakage Signals from

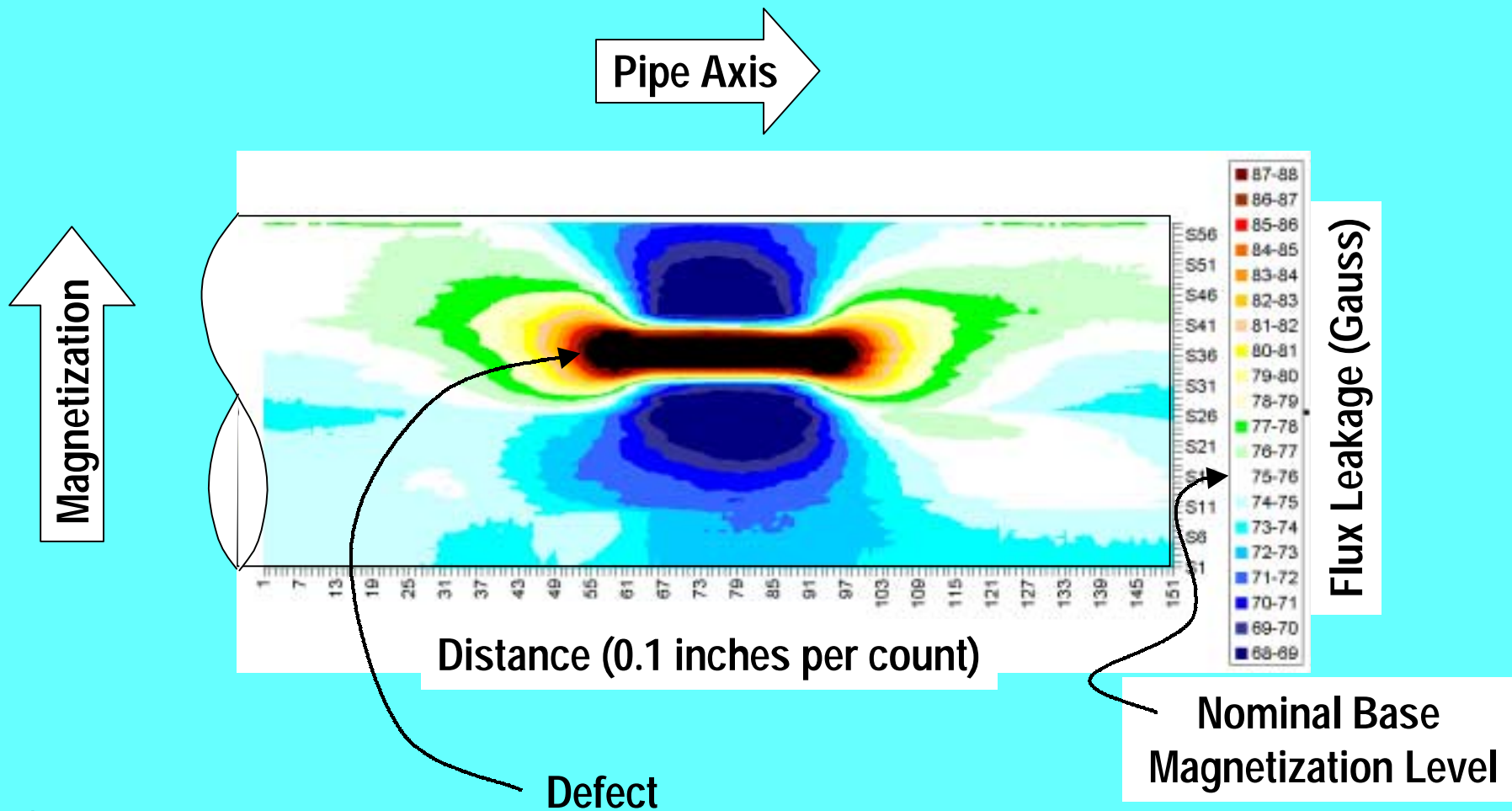
- **Artificial Flaws**
- **Natural Stress Corrosion Cracks and Corrosion**

Artificial Flaws

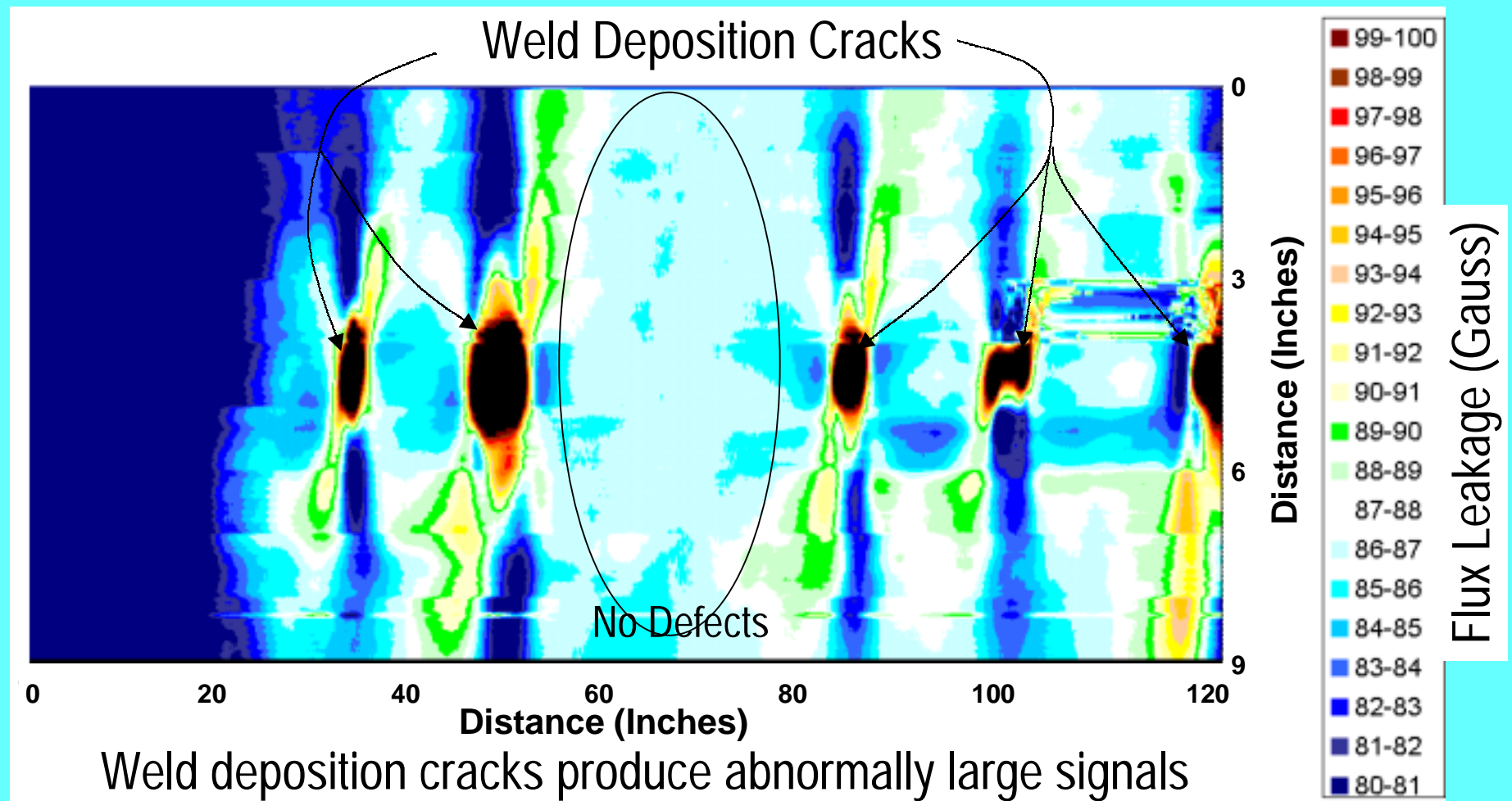
- Pipeline Simulation Facility Artificial Crack Sample
 - Weld Deposition Cracks
 - EDM Notches (0.020 inches wide)
Long two rows in the pipe and in the seam weld
- Made by SwRI



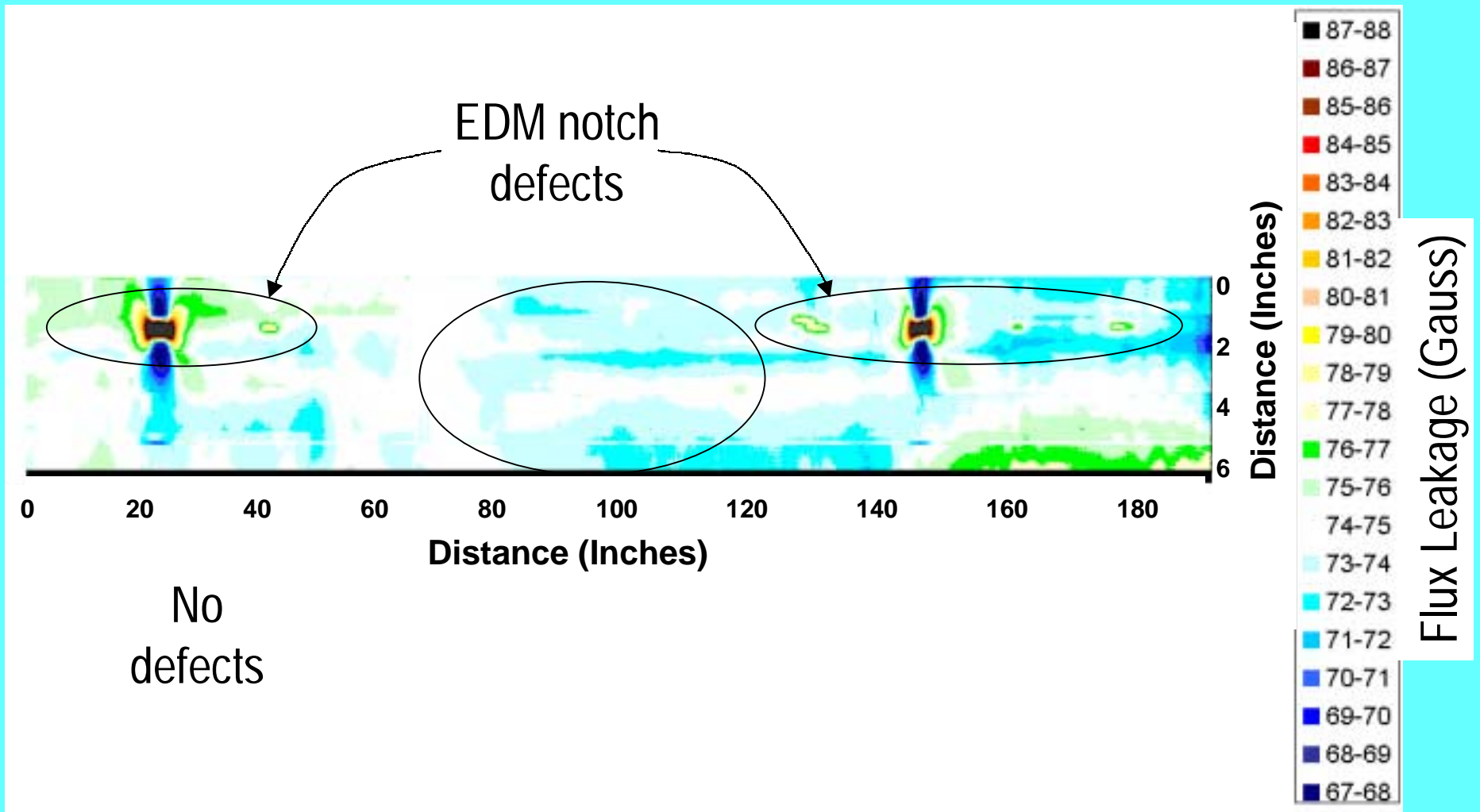
Graphical Data Display



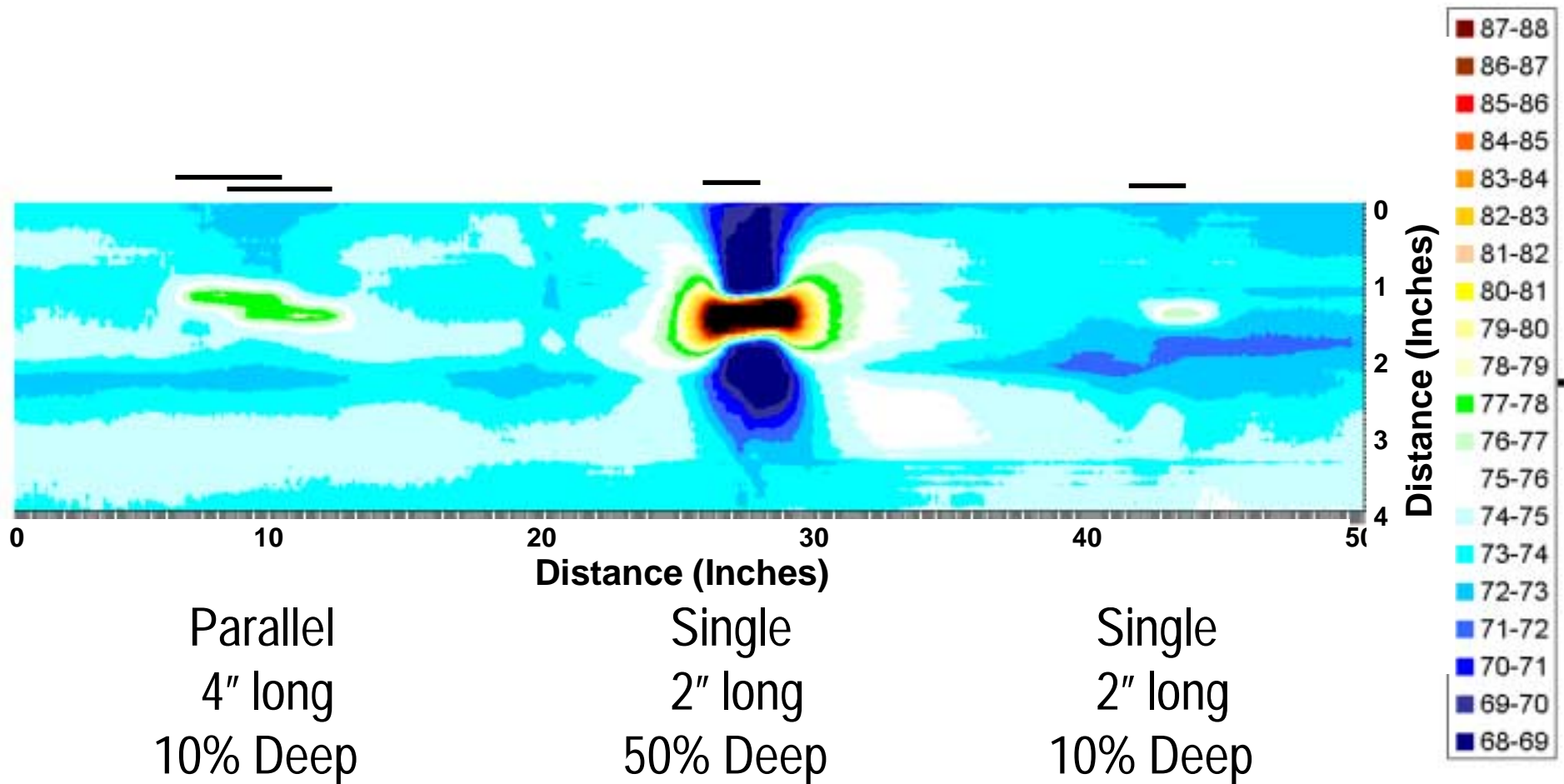
Weld Deposition Cracks



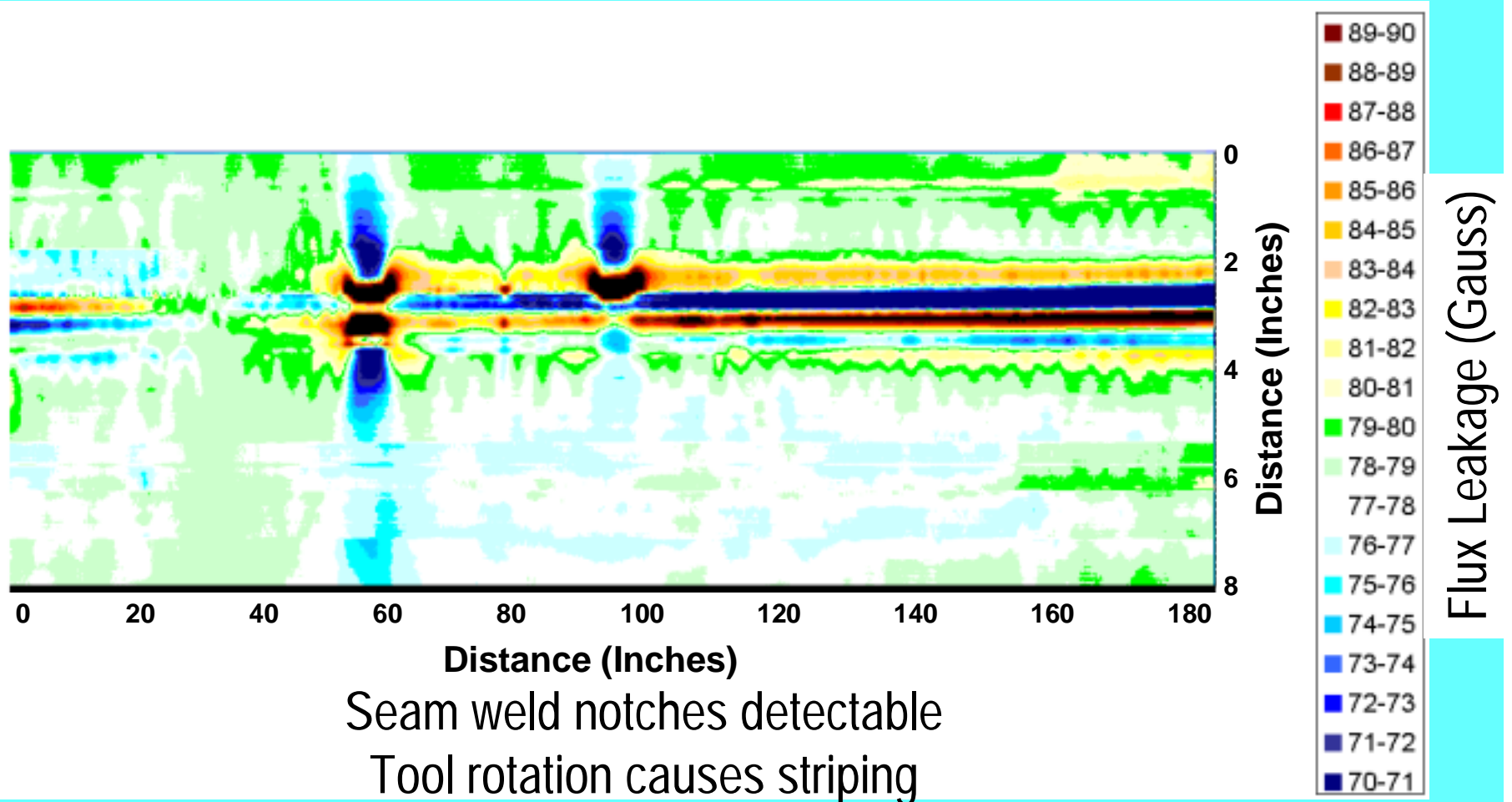
EDM Notches



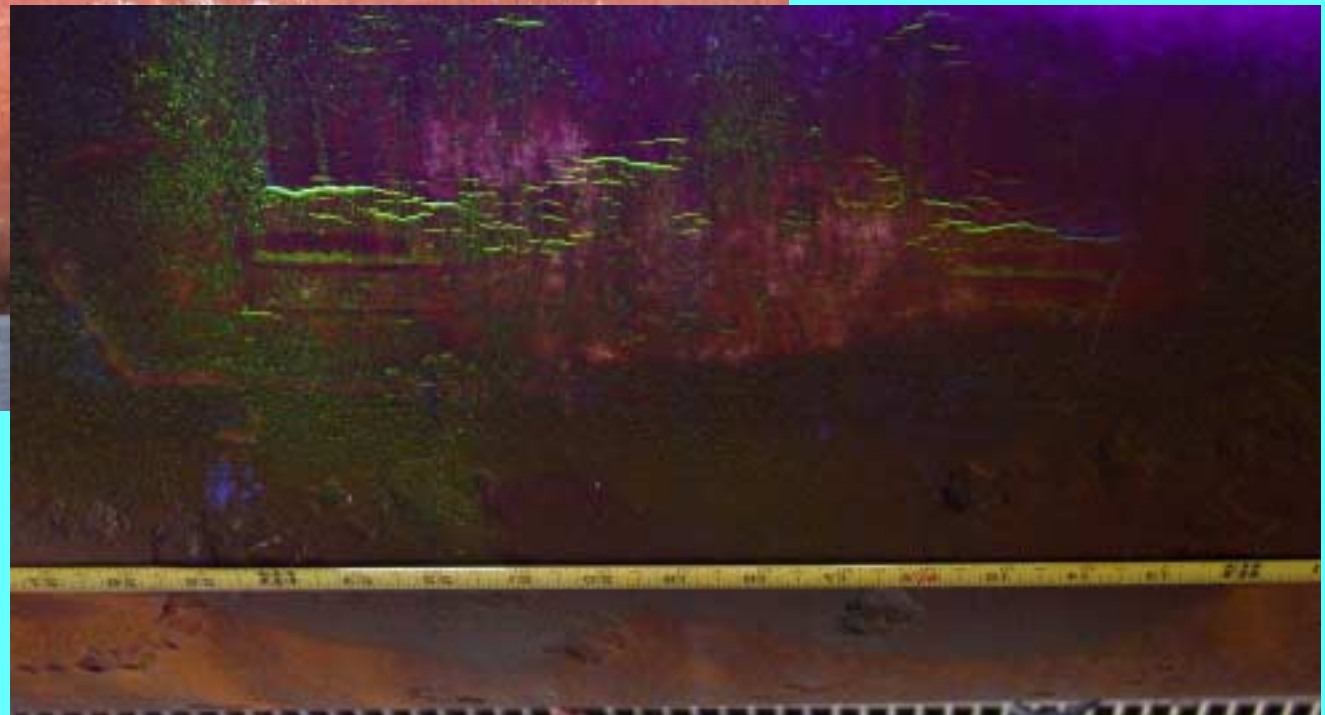
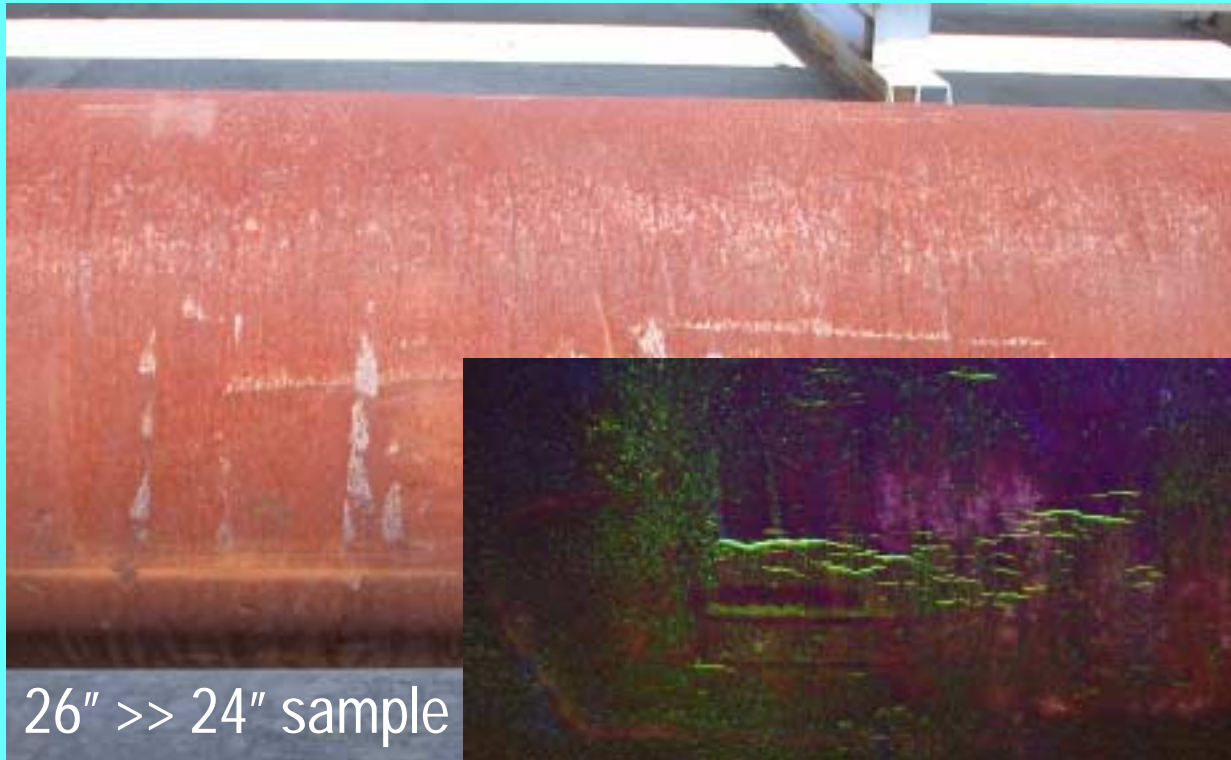
Close Up of EDM Notches



EDM Notches in the Weld Seam

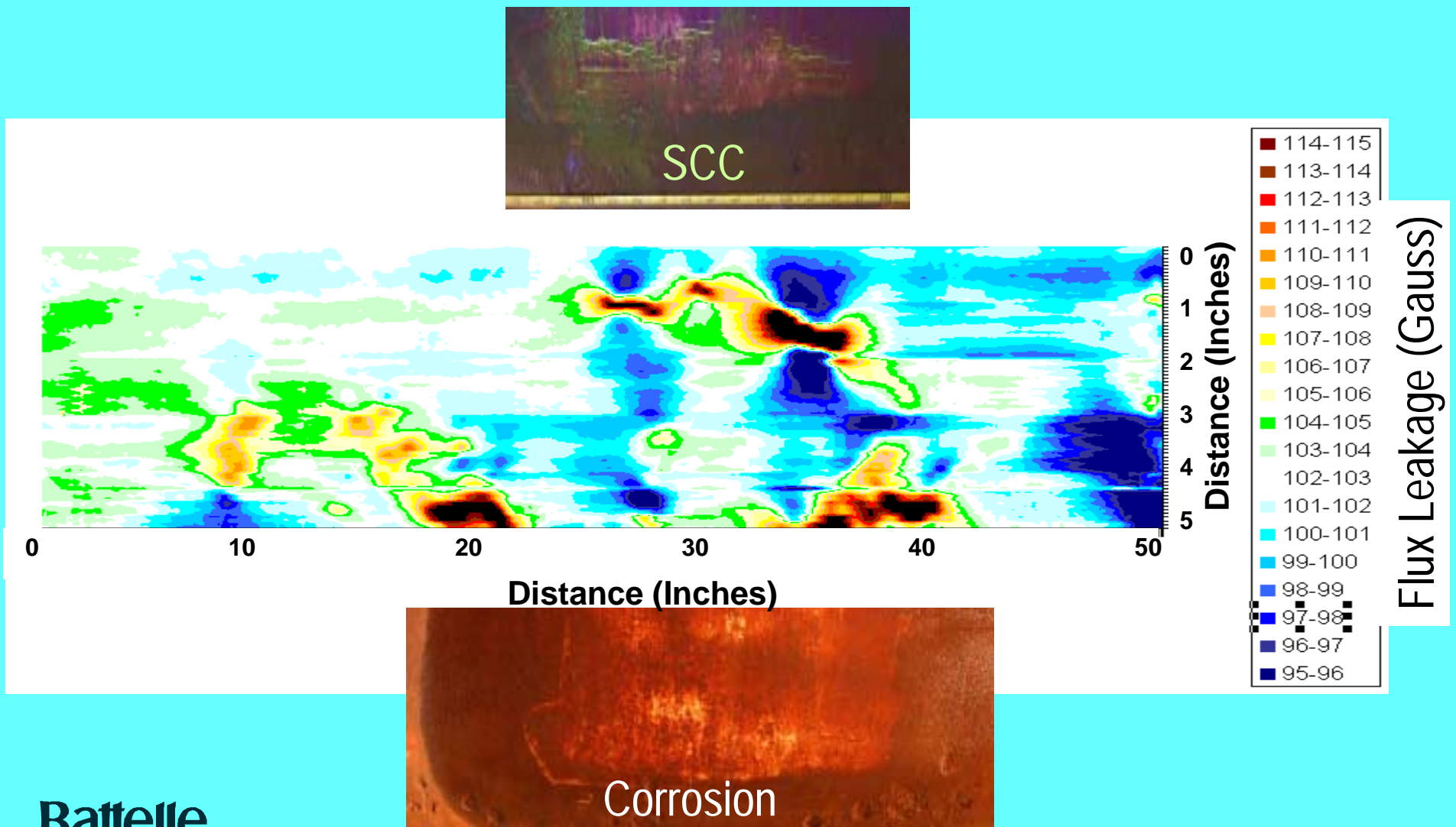


Natural SCC

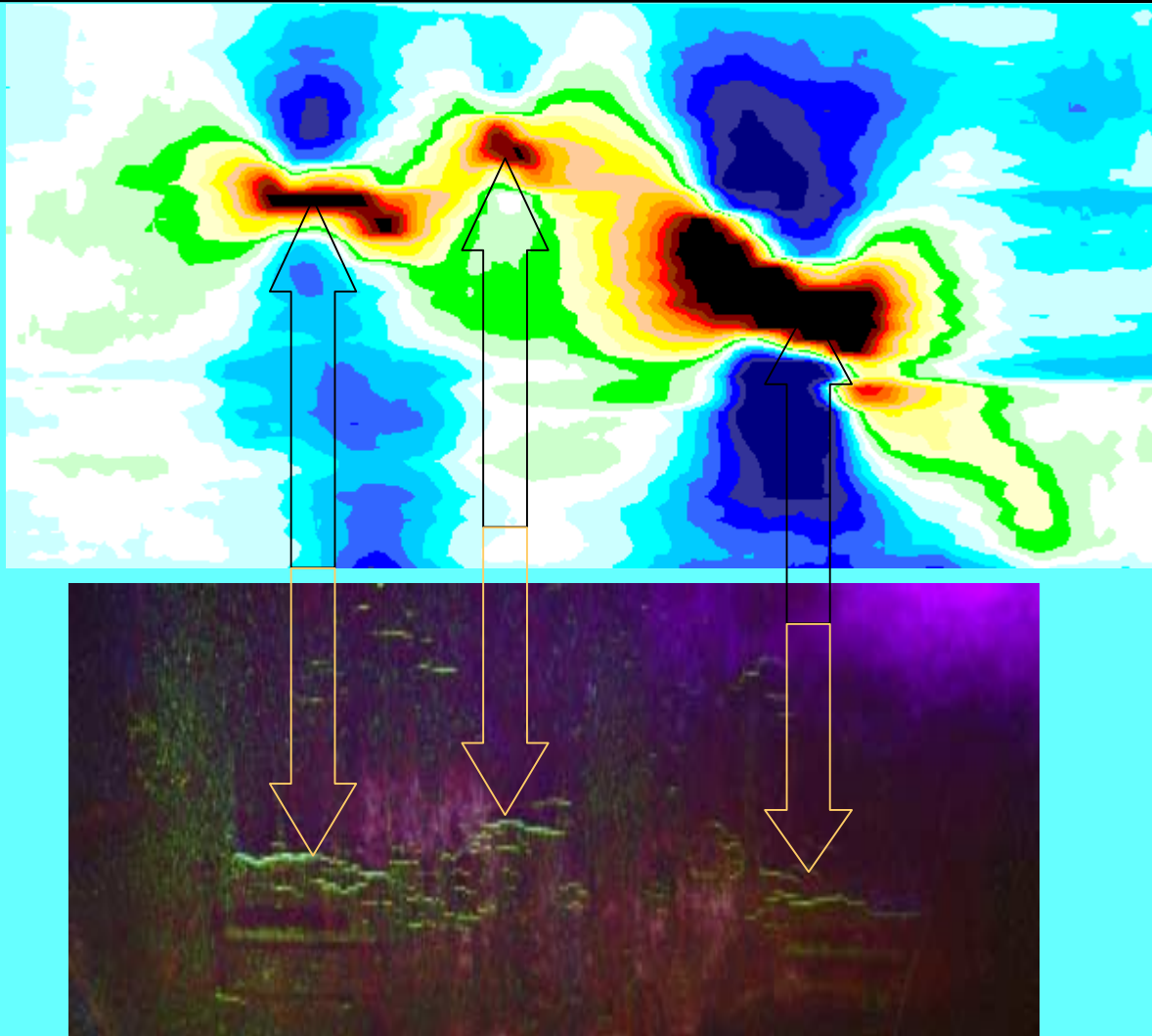


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Flux Leakage Image of Cracks and Corrosion



Flux Leakage Image of Stress Corrosion Crack Colony



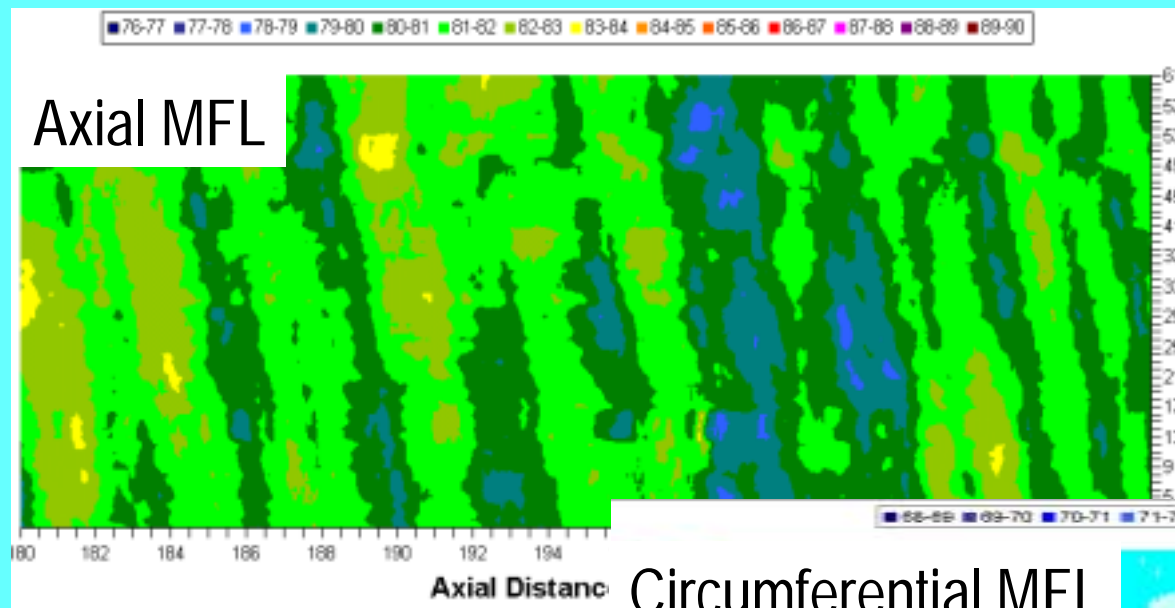
Summary of flux leakage from crack defects

- Weld deposition cracks, while tight as natural SCC, have magnetic property changes that do not simulate cracks well for flux leakage testing
- EDM notches have a more crack like appearance
 - Small notches can be seen (10%), opening may enhance signal
 - Notches in seam weld detectable
- Natural cracks can be detected
 - Cracks may have be opened and deepened when pipe made to be 24" from 26" diameter
 - Not all cracks detected
 - Multiple cracks look like corrosion
 - Depth not known

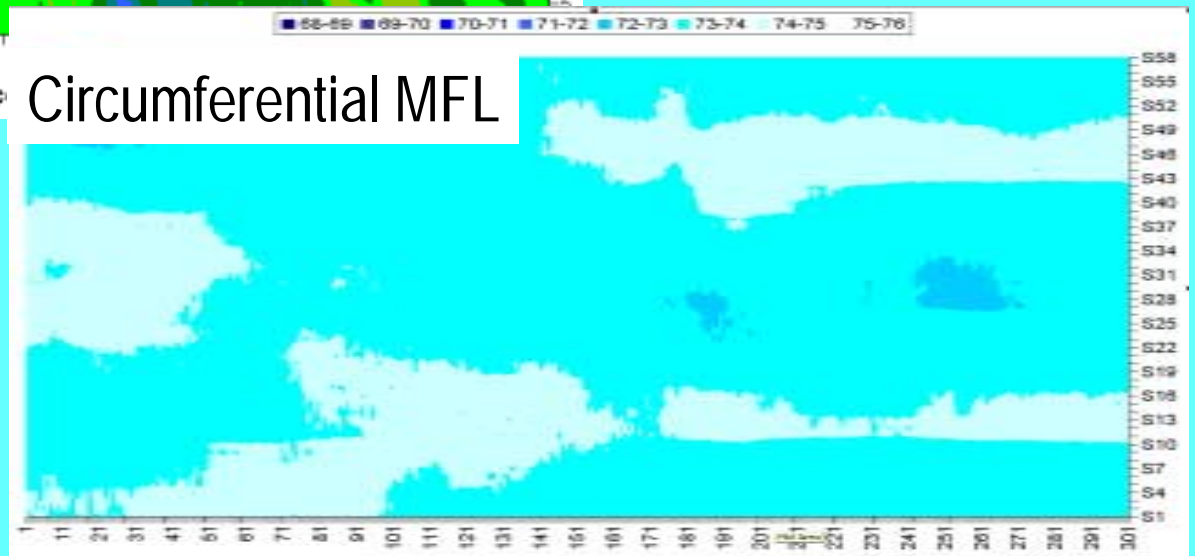
Pipe Noise – Magnetic signals for Circumferential and Axial MFL

- Detection of cracks depends on
 - The strength of signal from the smallest significant defect
 - Background noise of the material

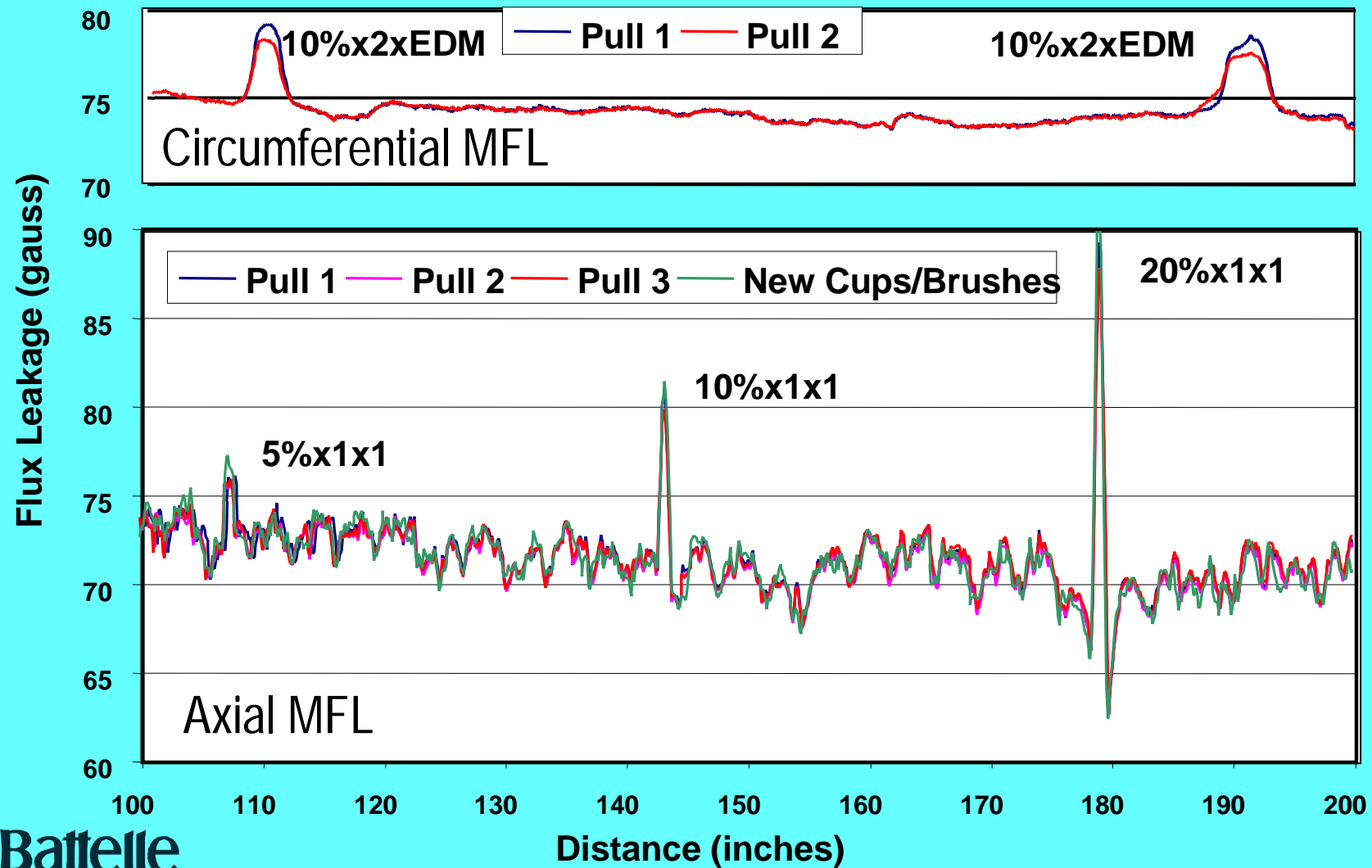
Typical Noise



Circumferential MFL



Axial and Circumferential Signals



Noise Summary

Pipe noise low in circumferential direction

- Four pipe samples tested in this program
- Circumferential magnetic noise levels 4-10 times lower than axial noise level
- Noise frequency is also lower. Since cracks provide abrupt signals, simple filtering may be sufficient
- Pipe noise levels approaching sensor noise levels of 0.2 to 0.4 gauss.

Conclusions

The pipe fabrication process makes

- Magnetization in the circumferential direction difficult.
 - Full saturation to eliminate magnetic differences is not attained for most pipelines
 - The ability to detect stress differences due to internal pressure may be difficult.
- High material noise signals for axial MFL but low material noise signals for circumferential MFL

Additional work

- There are still many things to be learned about circumferential MFL
- Inspection Variables
 - Stress effects (next)
 - Defect location relative to the poles
 - Velocity
- Defect Variables
 - Length and Depth
 - Opening
 - Separation of Cracks

